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temporal variability, Mississippi Bight, New York Bight, SeaWiFS, MODIS

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TEMPORAL VARIABILITY OF COASTAL WATERS IN MISSISSIPPI BIGHT AND NEW YORK BIGHT USING SEAWIFS AND MODIS

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ABSTRACT

We demonstrate the utility of SeaWiFS and MODIS to determine coastal optical properties for a one-year period. Optical properties derived from SeaWiFS and MODIS are compared for coastal waters in the Mississippi Bight and the New York Bight. A one-year time series from January 2001 to December 2001 with varying time scales (yearly, monthly, and eight-day composites) were processed with similar processing algorithms to determine the inherent optical properties (absorption and backscattering) of the coastal waters. The similar spectral and spatial resolution and repeat cycles of these sensors provide new methods to determine the temporal changes in the coastal processes.

We assess the temporal and spatial variability and regional dependence of the optics in both regions. Processing of MODIS and SeaWiFS imagery was performed using modified NASA standard atmospheric correction methods. For both satellites, a near-infrared (NIR) atmospheric correction method (Arnone et al, 1998) based on the assumption that the normalized water-leaving radiance, nL_W, at 765- and 865-nm is not zero in the high turbid waters was applied. For both SeaWiFS and MODIS, this correction reduces the number of negative radiance values and improves the estimation of optical properties in the highly turbid coastal region.

INTRODUCTION

With the first light image of MODIS in March 2000, the ocean color community was provided with an additional source of ocean color data similar in scale to that of SeaWiFS. We will soon have three views of the coastal processes from three separate sensors with the recent launch of a second MODIS instrument onboard AQUA. This will provide high temporal resolution as well as high spatial (one kilometer) resolution giving us the capability to more accurately assess the quickly changing coastal processes.

In this study, we will address the temporal and spatial variability of the two sensors for coastal monitoring separately so as to ascertain any differences in the ocean color estimates provided by each. This will lead us to an understanding of the differences between both systems and their processing methods. By using similar processing methods, we should determine the inherent differences in the systems.

Coupling two different sensors to measure quantitative ocean optical properties is a significant task. The MODIS and SeaWiFS sensors are very different both in design,

calibration and orbit. The MODIS sensor onboard Terra overpasses approximately 1.5 hour before SeaWiFS at 9:30 AM. This time difference in overpass can account for a 30% increase in the water leaving radiance, which results from higher sun angle. In this study, we will use the 8 spectral channels (the "ocean" bands) on MODIS which are similar to SeaWiFS in spectrum and ground resolution (1.1 km). There are differences in the pointing geometry and the avoidance of sun glint between the sensors. These differences are critical in ocean color processing for ocean properties since the procedures are based on absolute radiometric spectroscopy from space borne sensors. Accurate assessment of the sensors' calibration is required since the ocean color signature represents less than 7% of the total radiance at the top of the atmosphere. Errors in calibration must be maintained to less than 2% for both sensors in order for ocean retrieval to be comparable between both sensors. The removal of scattering from aerosols and Rayleigh as well as ozone correction is both angularly and temporally different for both sensors. Additionally, the assimilation of auxiliary data such as barometric pressure, wind, and ozone is likewise different for the each sensor. There are differences in the sensors design (spectral channels and cross-track geometric calibration) and procedures for internal and external calibration. Lastly, there are differences in the software processing between the two sensors. In order to retrieve compatible results between the sensors, all of these issues need to be accounted for correctly both in time and space.

Differences in the ocean properties can be real. That is the ocean optical properties can change on hourly time scales especially along fronts. Liu, Zhao, Esaias, Campbell and Moore have an article in press (EOS Transactions Newsletter) on tracking the gulf stream using MODIS and SeaWiFS which demonstrates these time scales.

The capability of having two satellite sensors for detecting ocean optical properties offers new potentials for understanding and monitoring the changing coastal ocean. It is critical that the two sensors be cross-calibrated so that the ocean products can be coupled and integrated for monitoring long- and short-term changes in ocean properties. We observed temporal changes to be the result of ocean changes and not the differences in sensor calibration, processing, or algorithms. We have tried to minimize the differences in the processing procedures (identical optical algorithms, very similar atmospheric correction procedures, etc.)

The differences in ocean properties change both temporally and spatially. Results from an individual image may illustrate very similar comparison whereas other individual images may be very different. We have elected to conduct a statistical comparison which compares a sequence of imagery (200 MODIS and SeaWiFS) covering the yearly seasonal response which results in differences in solar elevation, varieties of winds and climatic conduction, and a wide range of ocean properties. By evaluation of the yearly time series we can evaluate the statistical response of these two sensors. We are trying to remove the bias in the comparison by averaging over localized ocean/atmospheric events and evaluating the sensors on oceanic basin scales. The evaluations of global scales comparison will require longer analyses to account for more subtle changes occurring within the central ocean gyres.

The objective of this effort is to characterize the differences in derived MODIS and SeaWiFS optical properties. Our analyses will define differences and bias of the sensors on seasonal bases in both coastal and open waters.

METHODS

The SeaWiFS data was processed using the Navy's Automated Processing System[10] (v2.6). For SeaWiFS, the methodology is based on the NASA 3rd reprocessing codes with the following exceptions. First was a change to a reflectance-based NIR iterative correction[1]. Secondly, a new vicarious calibration based on NRL's in-situ database and the addition of Carder's absorption and scattering algorithms.

The NIR iterative correction is based on reflectance, unlike Siegel's chlorophyll based iterative correction used by the NASA 3rd reprocessing codes. In the standard Gordon/Wang atmospheric correction[6], an assumption that the reflectance at the NIR bands (7 and 8, 765- and 865-nm, respectively) is due solely to atmosphere is made. That is, the water reflectance is zero. The NIR iteration uses the Gordon-estimated reflectance at 670-nm and the spectral nature of scattering[7] to estimate the water-reflectance in these "atmospheric" bands. Consideration of the total absorption at 670-nm is also made. This absorption is due to phytoplankton, CDOM, and water. For the atmospheric bands, the absorption is assumed due to water only, which is highly absorbing at these bands.

The vicarious calibration[8] was based on over 75 stations in the Gulf of Mexico, East Sea, and New Jersey Coast. The in-situ reflectance values were derived from above-water measurements taken with a hand-held spectroradiometer. The vicarious calibration gains were iteratively changed until the ratio of the SeaWiFS derived reflectance over the in-situ reflectance at each band approached unity. This vicarious calibration was based on remote sensing reflectance measurements and not on the MOBY data, which has since been corrected for a stray light condition. It is interesting to note that the NRL vicarious calibrations are similar to the new gains for NASA's 4th reprocessing codes especially at the 412-nm band.*

The SeaWiFS chlorophyll *a* codes were obtained from Carder and added to the NASA sources. Additionally, it was modified to return the backscattering and absorption components for each band. These inherent optical properties were secondary components derived by Carder's algorithm. All Level-1 SeaWiFS data was collected at NRL receive site in the Gulf of Mexico. We processed approximately 30 scenes per month from January through December 2001.

The MODIS data was also processed using the Navy's Automated Processing System (v2.6). For MODIS, the processing software is based on the University of Miami's "modcol" program with the following exceptions: (1) addition of the Arnone reflectance based NIR iterative atmospheric correction described above and (2) a change to Carder's code to export the backscattering terms in addition to the absorption terms. The Miami code was received at the end of May 2002. This release was just prior to the release of the MODIS Ocean Products collection 4. All Level-1 MODIS data was ordered from the Goddard DACC (accounts for Level-0 to Level-1 MCST conversion.) Approximately 175 granules per month (2-4 per day coverage the Gulf) were processed from January to December 2001.

In both SeaWiFS and MODIS processing, the standard masks were used. These include cloud detection, atmospheric algorithm failure, land, and areas of high glint contamination. Additionally, during the averaging process (Level-3 to Level-4), those

* 1.3% and 1% higher for NRL and NASA 4th reprocessing gains than the NASA 3rd reprocessing gains.

pixels with high sensor angle, poor or suspect navigation were excluded from the statistical analyses.

Figure 1, demonstrates the effect the Arnone NIR algorithm on a scene from the Mississippi Bight (1 October 2001). The images (top to bottom) represent, diffuse attenuation at 532-nm, total absorption at 443-nm, chlorophyll-a concentration, and remote sensing reflectance at 412-nm. The images in the left column were processed using the Arnone NIR iterative correction; the images in the right column were processed using the default MODIS processing atmospheric correction.

The NIR correction has a dramatic effect on the retrieval of the reflectance in the coastal regimes, as evident in 412-nm remote sensing reflectance. There is little to no effect in the offshore regions. Because the NIR correction affects the entire spectrum, improvements are seen in the other products as well. The overall improvement seen in these MODIS images has been likewise seen in the SeaWiFS data – both processing methods use the Gordon atmospheric algorithm.

The Automated Processing System is an ocean color satellite processing system for regional areas of interest at full resolution. It generates products that address Navy needs (diver visibility, beam attenuation). The system can process data from Level-1 to Level-3 (map-projected geophysical parameters) and Level-4 (averaged). The Level-4 data consists of composites of individual scenes averaged at various temporal resolutions. Currently these include daily, weekly (8-day), monthly, and yearly composites. Various quality checks are performed on the input data including range checking and other flags.

The Carder algorithm is known as a semi-analytical algorithm, which separates the remote sensing reflectance into its two primary components, total absorption and backscattering. Additionally, the algorithm can decompose the total absorption into three of its four components, namely, water absorption, phytoplankton absorption and a combined term of detritus and gelbstoff[4]. From the phytoplankton absorption, the algorithm derives the chlorophyll-a concentration. For MODIS, the algorithm has the additional ability to use the sea surface temperature provided by the MODIS instrument for nitrogen-depletion to ascertain the chlorophyll packaging effect. Thus, the algorithms as implemented for the two sensors are slightly different.

RESULTS

For this extended abstract, we consider the results of the first 14 weekly composites from January 2001 to late April 2001. To assess the temporal and spatial variability of coastal waters, several regions of interest were considered. These include: (1) Mobile Bay, a coastal estuary with very high scattering suspended sediment waters (1671 pixels); (2) Lake Pontchartrain, a coastal estuary with high sediments and CDOM absorption (2915 pixels); and (3) Northeast Gulf of Mexico consisting of shelf waters in a 2 by 4-degree box (164160 pixels) as shown in Figure 2. This offshore box provides a control area to ascertain the differences in algorithms and sensor characteristics. In these offshore waters, the effect of the NIR atmospheric correction is much reduced. For each region, the average, standard deviation, and number of pixels used in the statistical computations were computed (omitting the flagged pixels)

In Figure 3, the weekly average diffuse attenuation at 532-nm for the Northeast Gulf of Mexico region is plotted for SeaWiFS and MODIS. The plot shows a similar

seasonal trend between the two satellites with values ranging from 0.1 to 0.2. The diffuse attenuation at 532-nm is computed from SeaWiFS K490 algorithm with the spectral shift to 532-nm as provided by Austin and Petzold (1984). Because these two algorithms have identical coefficients and computations between the SeaWiFS and MODIS processing, this very high correlation implies a very high correlation at least of the 490 to 555 ratio between the two satellites. Therefore, in offshore waters, the atmospheric algorithms give similar results.

For the coastal regions, a similar seasonal trend occurs again. In Figure 4, all the data from all regions are plotted with a trend line. This implies that the reflectance-based NIR algorithm, which has its greater effect in the coastal waters, yields similar results for SeaWiFS as well as with MODIS.

Figures 5 and 6 show our early results of the absorption at 443-nm and backscattering at 555-nm for the three different regions for the first 14 weeks of 2001. The Mobile Bay area is characterized by the lowest absorption values (0.1); the strongest absorption values (0.18) are in the Northeast Gulf of Mexico. This follows the trend of the chlorophyll *a*, Figure 7.

CONCLUSIONS

These analyses show:

1) MODIS and SeaWiFS retrieves bio-optical properties are in good agreement in both coastal water and shelf waters.

2) Coupled time-series of these sensors can be used to monitor changes in the ocean optical environment.

3) Both sensors can be used in coastal and estuarine waters if the NIR correction is used in the processing.

4) Comparison of MODIS and SeaWiFS must be performed on a statistical monthly analysis over a seasonal cycle to determine sensor and algorithm performance.

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Figure 1. Effect of NIR iterative correction using MODIS data. The images in the left column were processed with the NIR algorithm. The right column is the standard NASA MODIS processing.

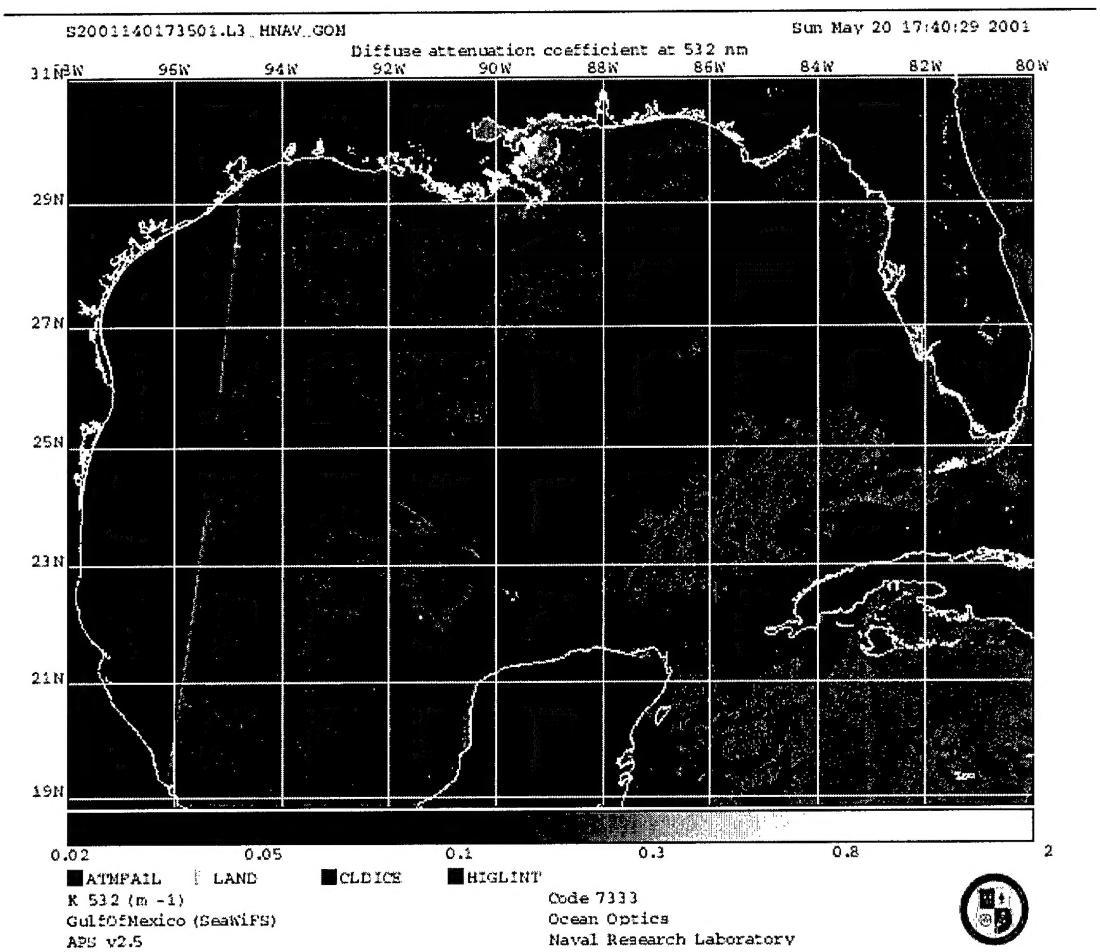


Figure 2. Locations of regions of interest used to compute time series.

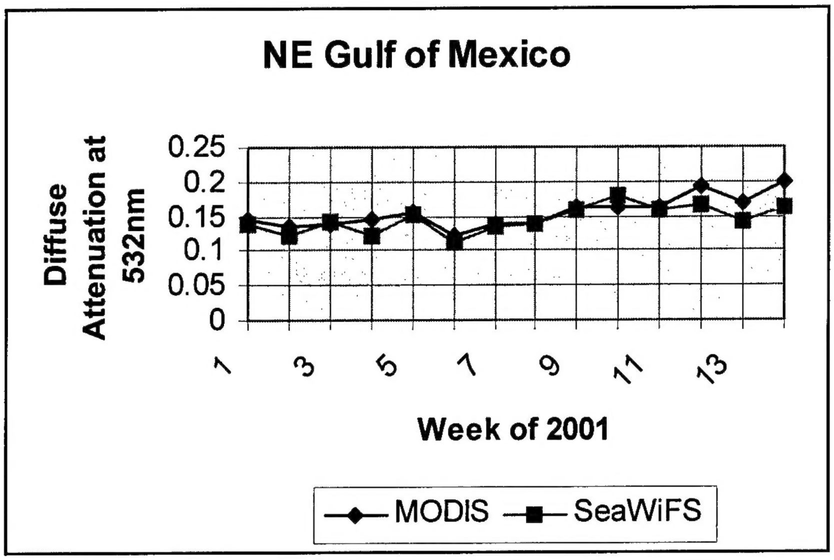


Figure 3. Average diffuse attenuation at 532nm for weeks 1 to 14 for Northeast Gulf of Mexico

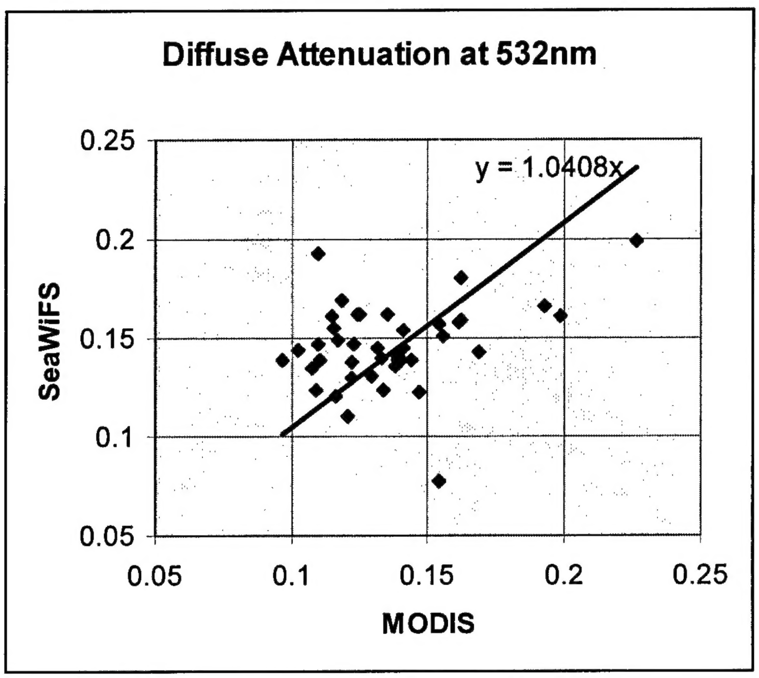


Figure 4. Plot of diffuse attenuation coefficient at 532-nm for all regions for all weeks.

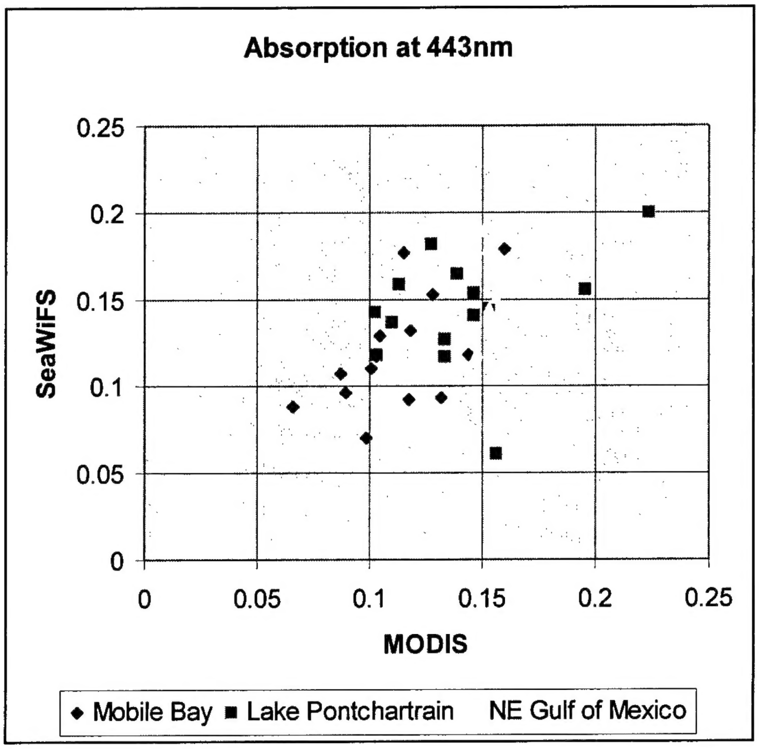


Figure 5. Total absorption at 443-nm.

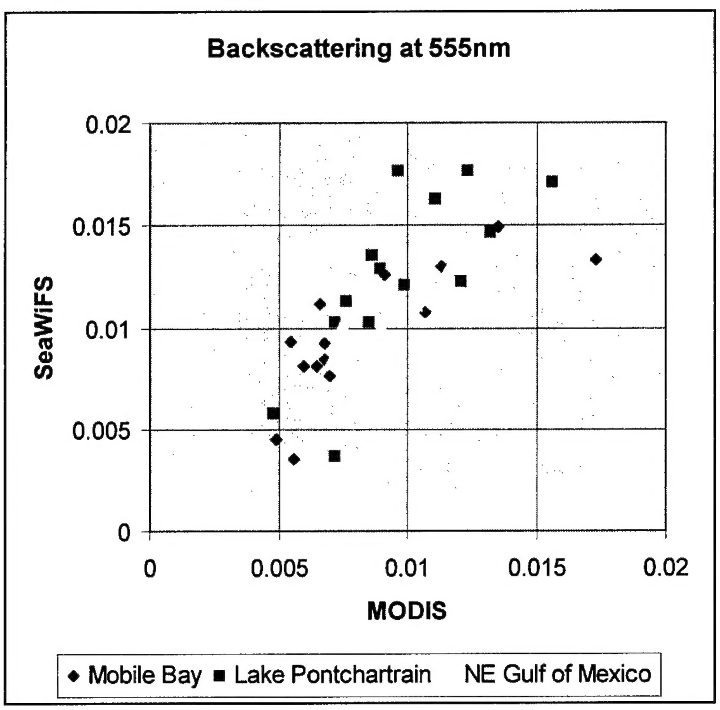


Figure 6. Backscattering at 555-nm.

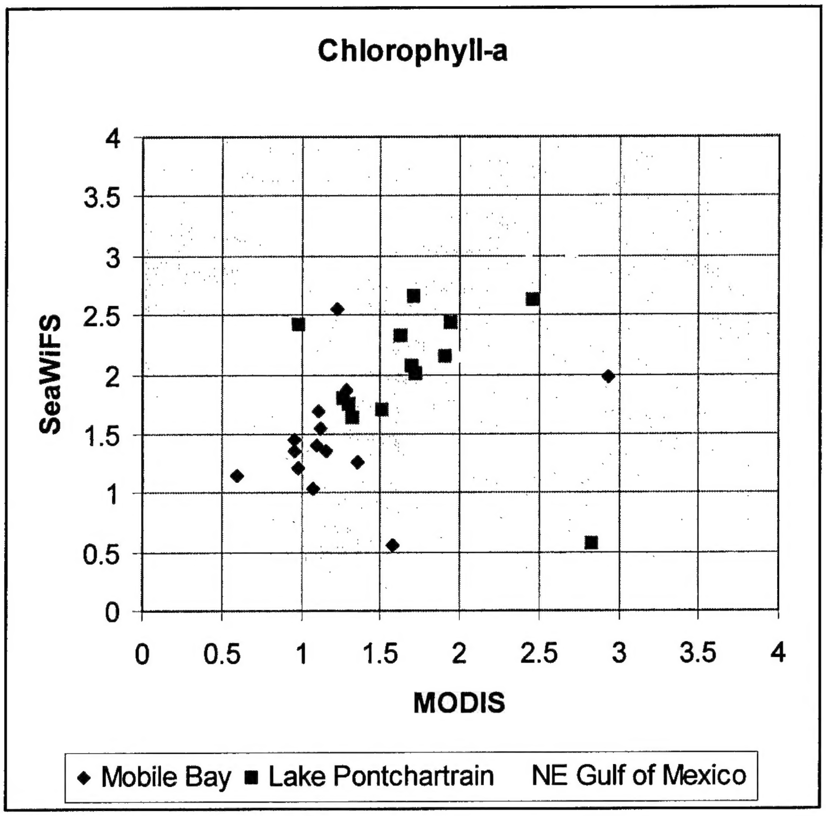
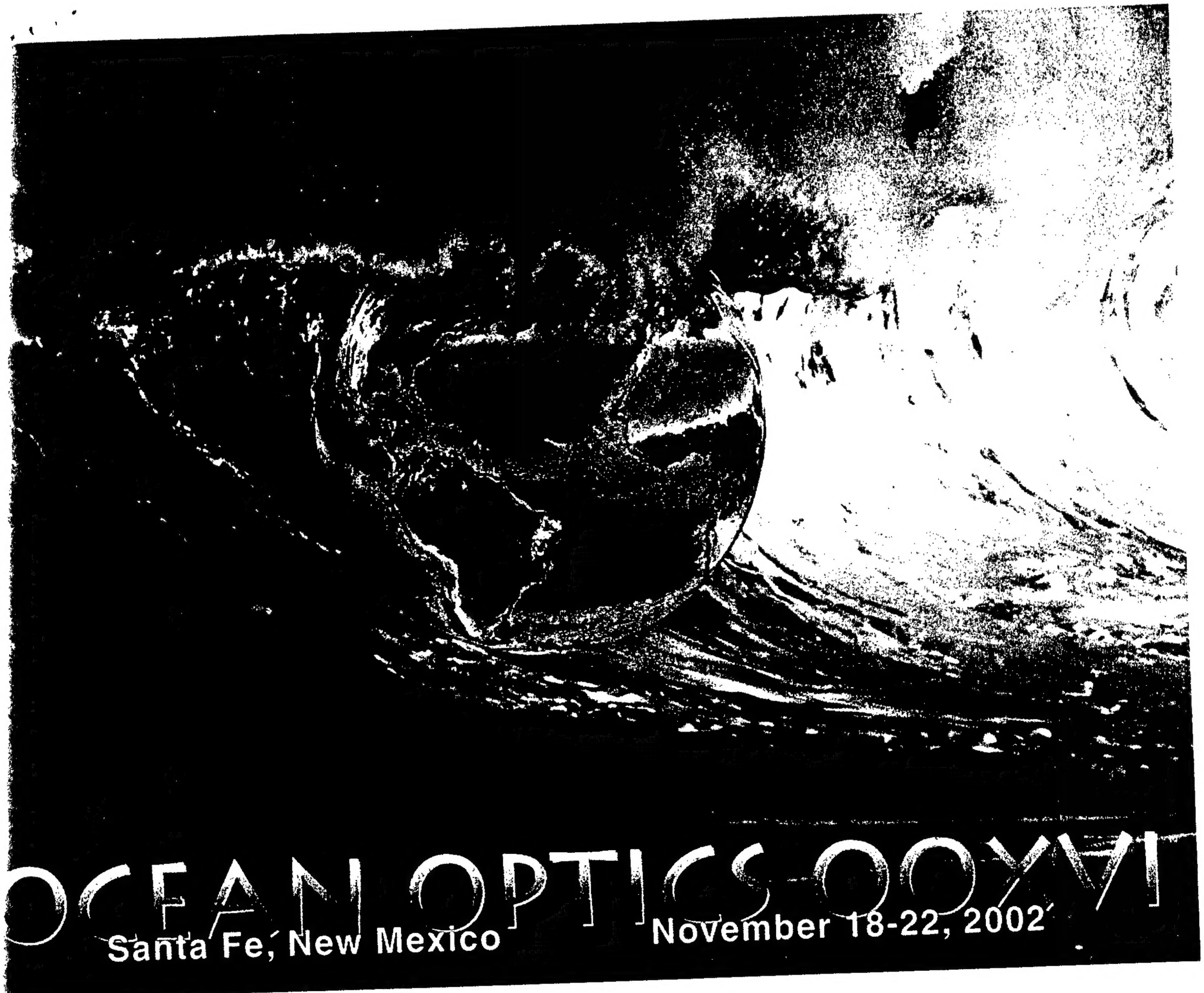


Figure 7. Chlorophyll-a concentration



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Program and Abstracts

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